

# A Statistical Approach For Reducing Angle-Dependent Biases In Satellite Cloud Optical Depth Retrievals

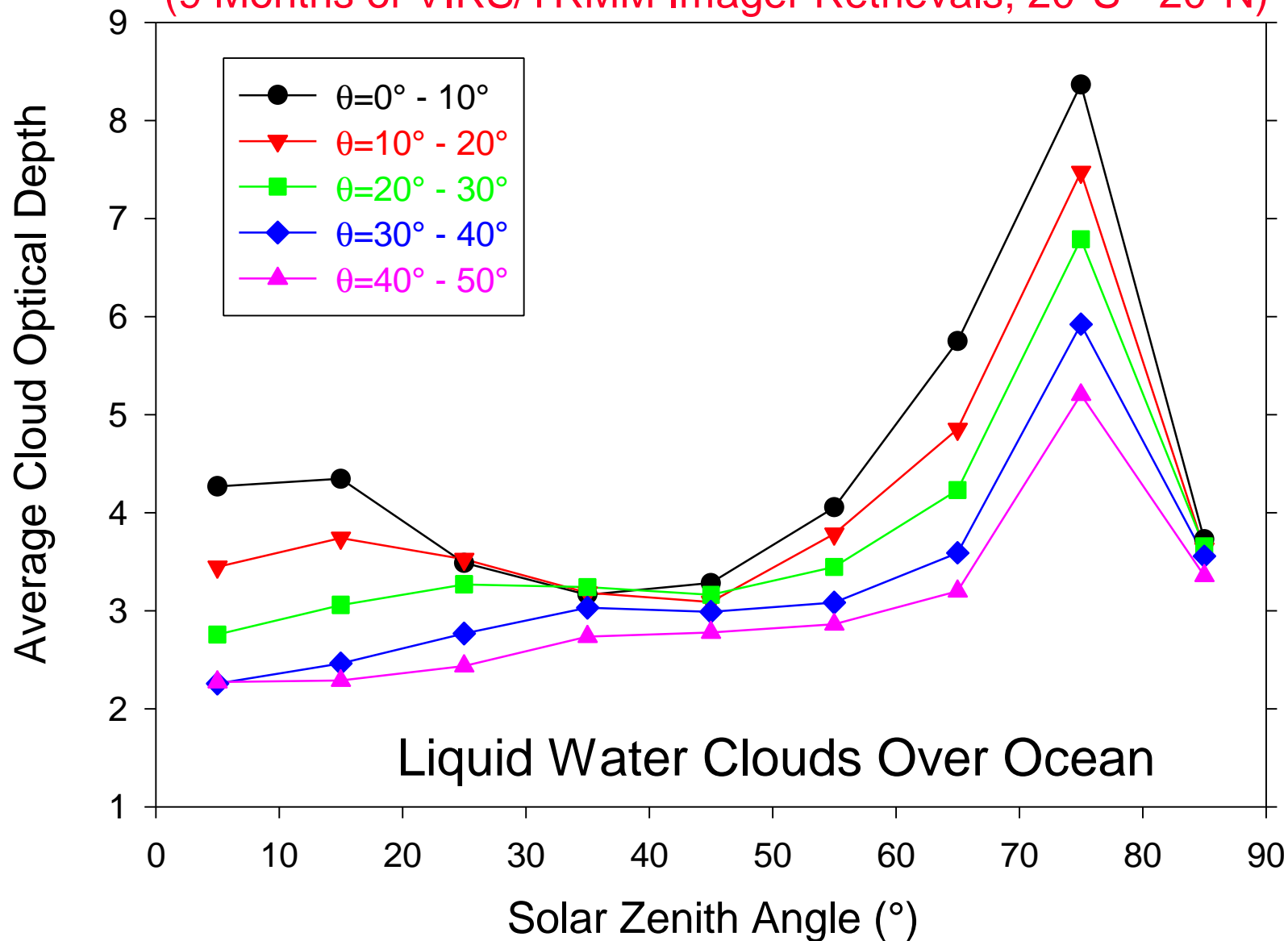
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## Background

- Current methods of estimating cloud optical depth from satellite measurements produce biased results that depend strongly on satellite viewing geometry.
- Previous theoretical and observational studies have demonstrated that the plane-parallel model approach:
  - Overestimates cloud optical depth at large solar zenith angles.
  - Produces inconsistent results at different viewing zenith and relative azimuth angles.

Tropical Average Cloud Optical Depth vs Solar Zenith Angle  
(9 Months of VIRS/TRMM Imager Retrievals; 20°S - 20°N)



So, what do we do?



## Some Options

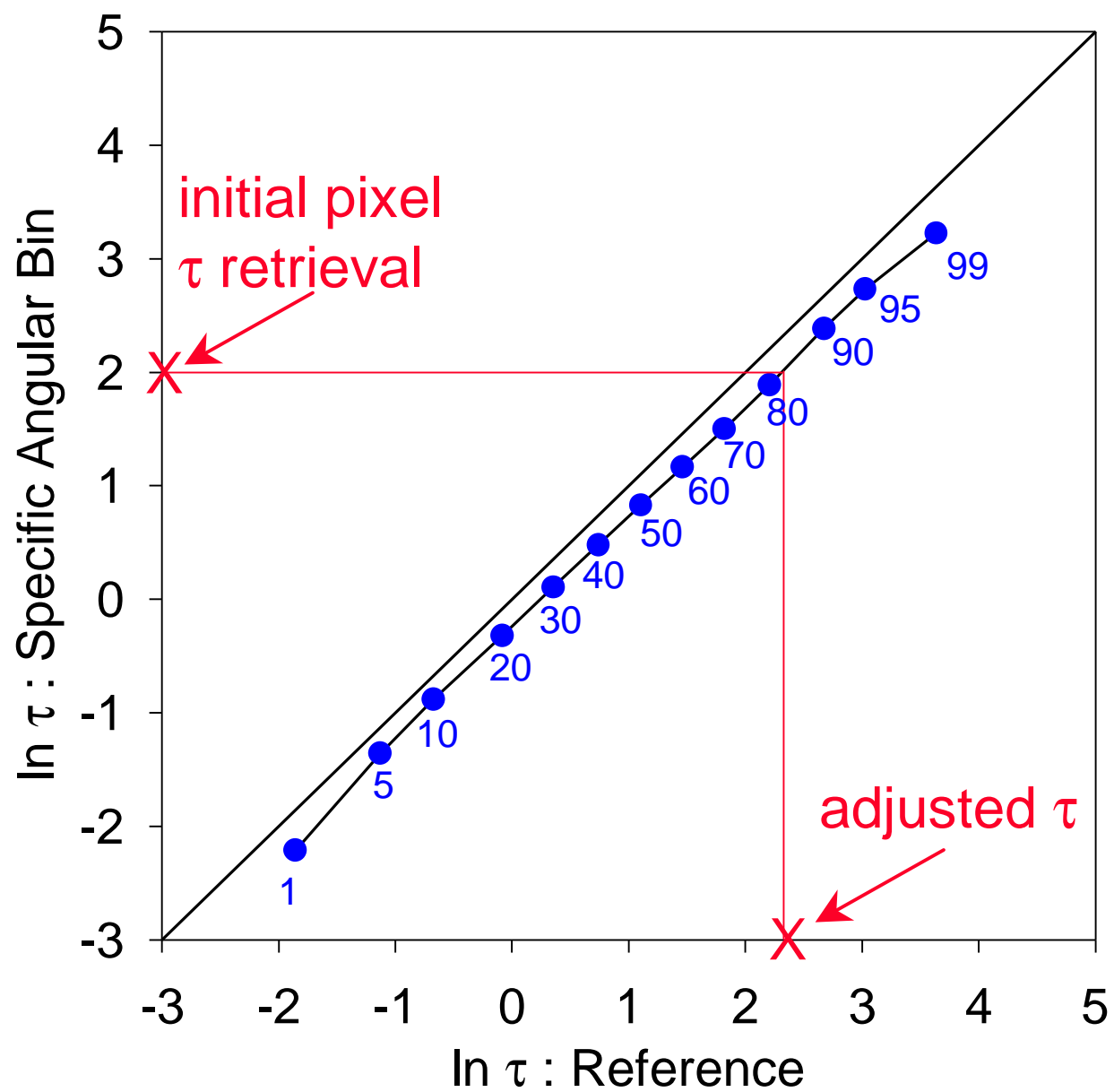
- Perform retrievals using theoretical models that account for 3D cloud effects.
  - Can be computationally expensive.
  - How are the calculations initialized?
- Statistical corrections to 1D retrievals.
  - Consider a large ensemble (several months) of satellite measurements.
  - Assume true cloud optical depth is independent of sun-earth-satellite viewing geometry.
  - Develop “corrections” to 1D retrievals that force ensemble cloud optical depth distributions to be self-consistent in all viewing geometries.

## Observations

- Nine months of cloud optical depth retrievals inferred from Visible Infrared Scanner (VIRS) measurements aboard TRMM spacecraft (January-August 1998, and March 2000)
- Latitudes restricted to 20°S - 20°N
- Cloud optical depths based on operational CERES cloud algorithm (Minnis et al., 1998)
- Main advantages of VIRS:
  - 35° inclined orbit:
    - => 46 day precession cycle
    - => it takes approximately 23 days to observe a location from all available solar zenith angles between 0-90°
- Disadvantages:
  - => Viewing zenith < 45°; 2-km spatial resolution

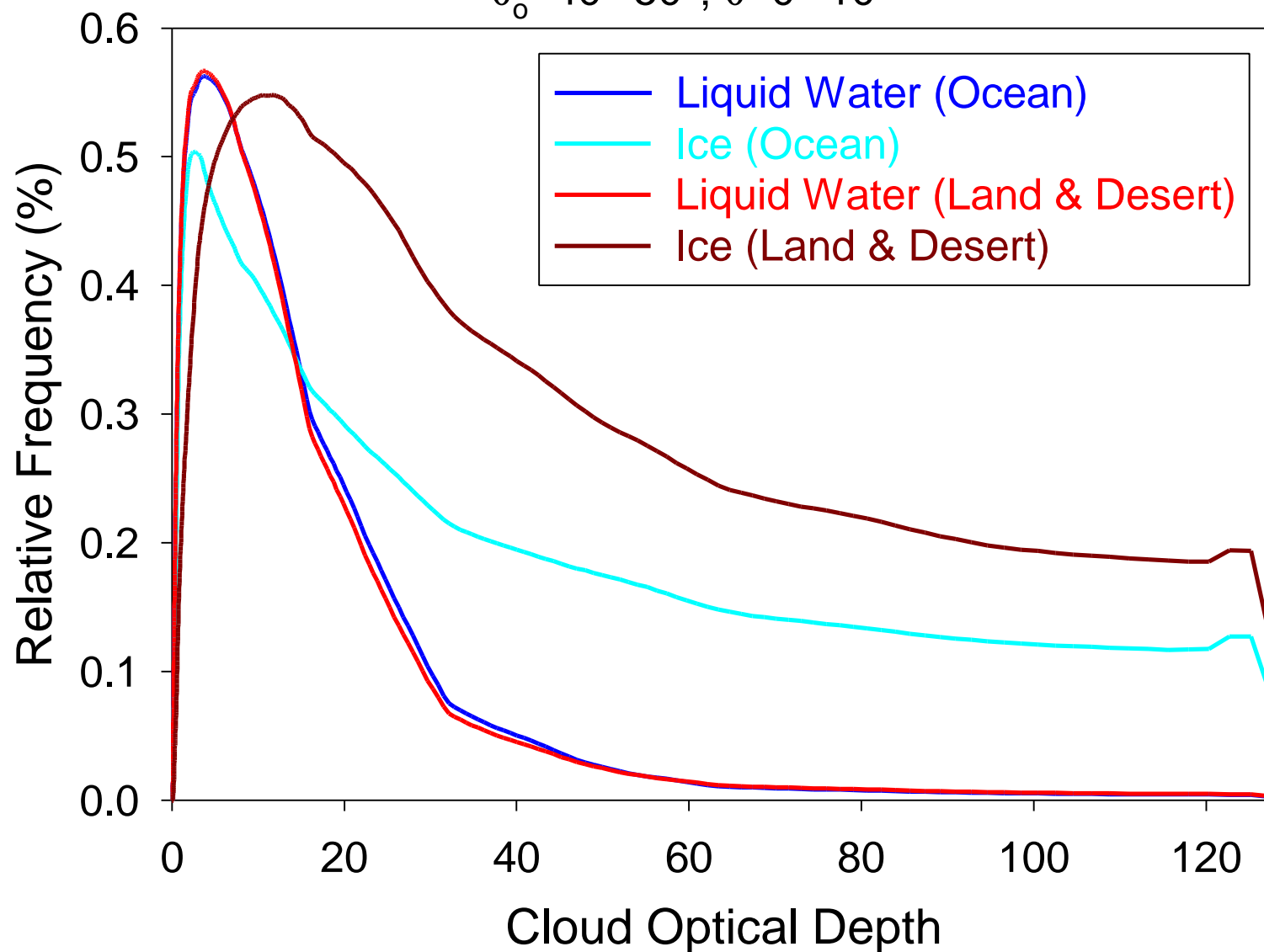
## Approach

- Determine  $\tau$  frequency distributions from 9 months of imager retrievals stratified by VIRS viewing geometry.
- Define reference cloud optical depth distribution. Here we use VIRS retrievals for  $\theta_o=40^\circ-50^\circ$ ;  $\theta=0^\circ-10^\circ$ .
- Plot  $\tau$ -percentiles from each VIRS angular bin against  $\tau$ -percentiles from the reference distribution. Use these curves to apply  $\tau$ -correction.



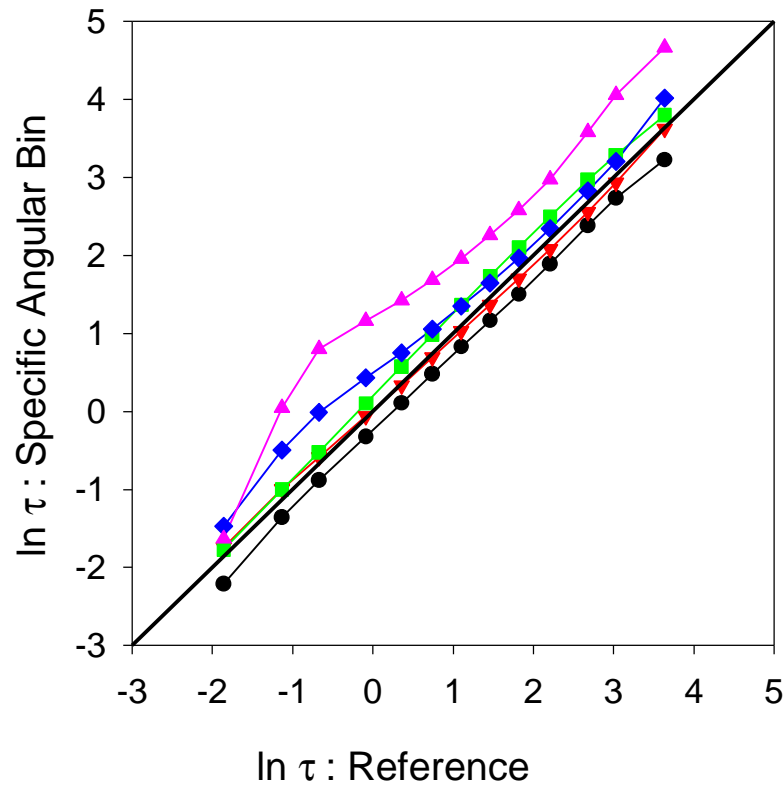
## Reference Cloud Optical Depth Distributions

$\theta_o = 40^\circ - 50^\circ$ ;  $\theta = 0^\circ - 10^\circ$

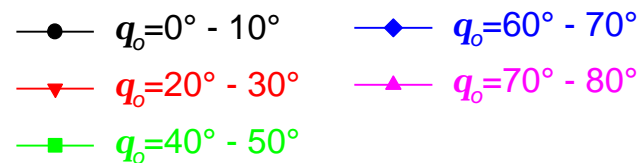
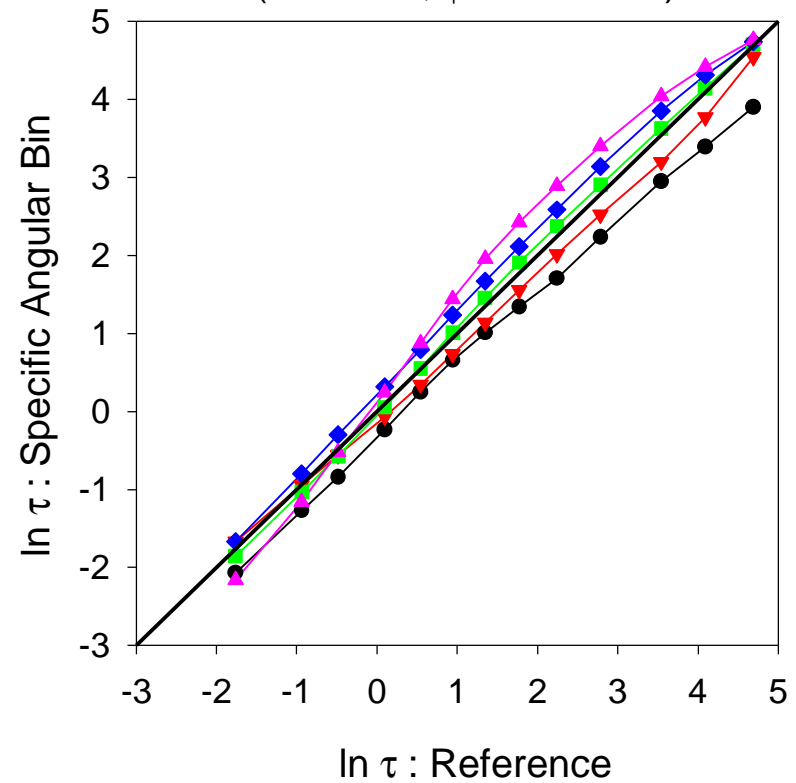


## Correction Curves: Ocean

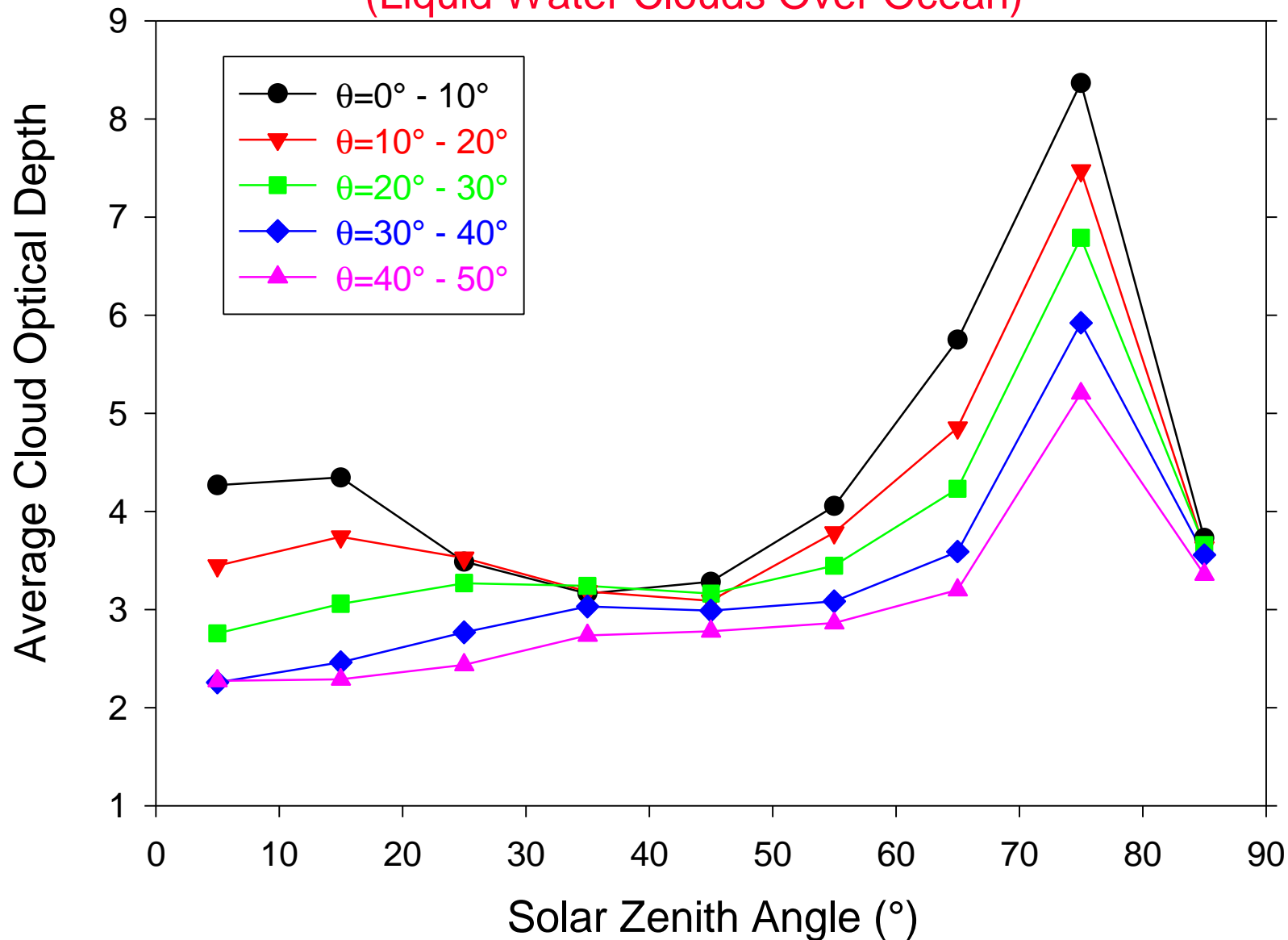
Liquid Water Clouds Over Ocean  
( $\theta=0^\circ-10^\circ$ ;  $\phi=150^\circ-170^\circ$ )



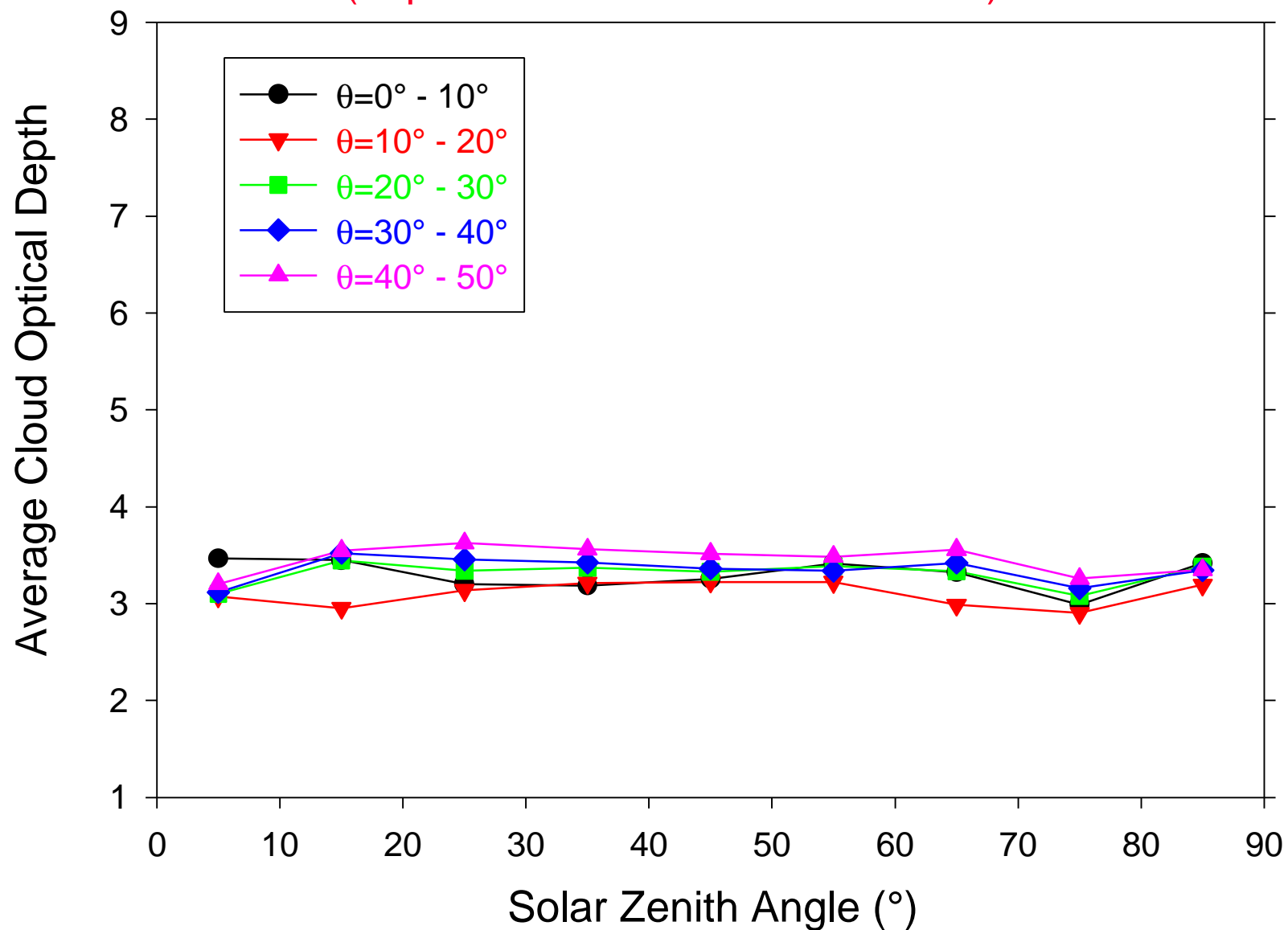
Ice Clouds Over Ocean  
( $\theta=0^\circ-10^\circ$ ;  $\phi=150^\circ-170^\circ$ )



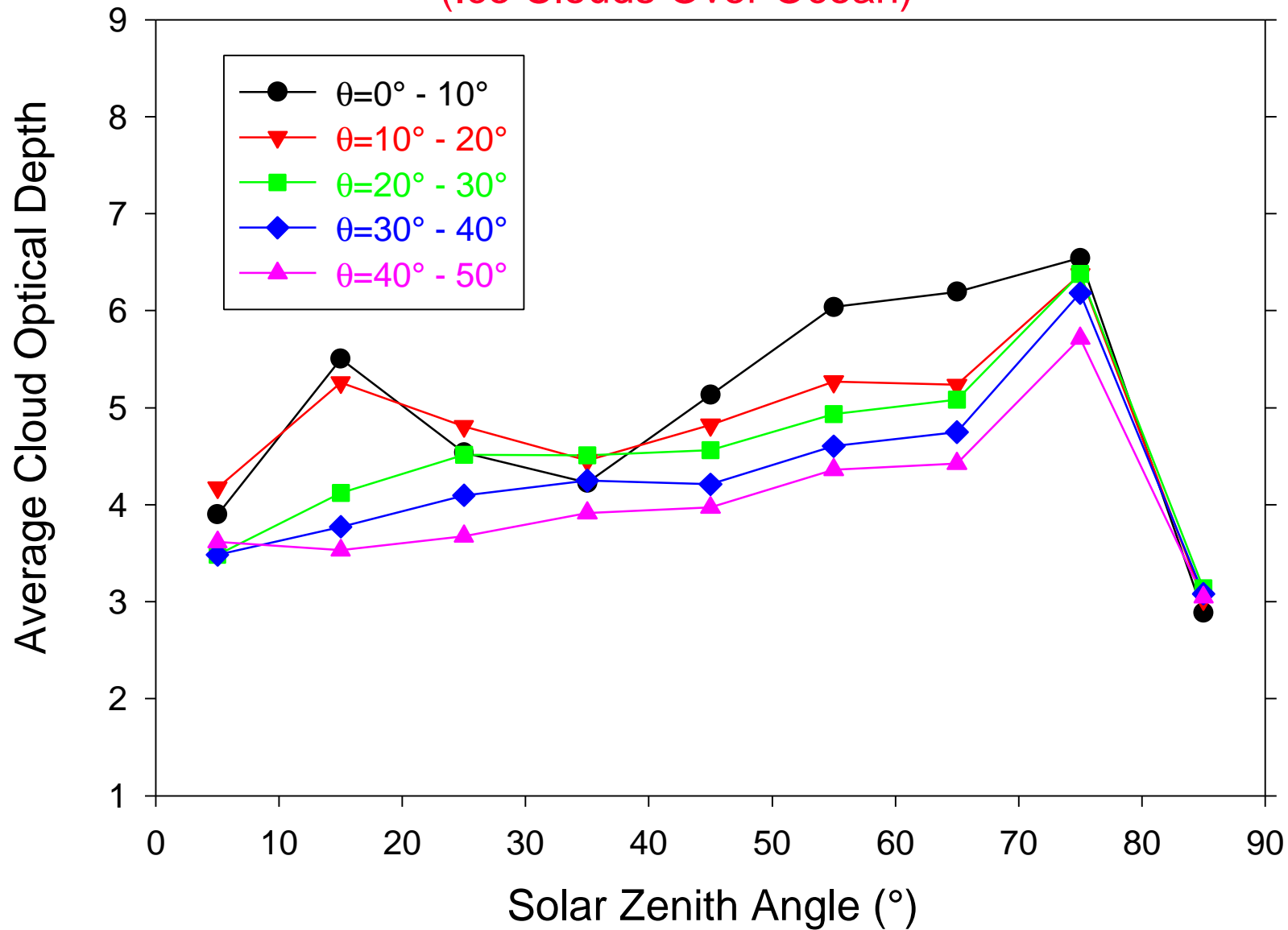
## Tropical Average Cloud Optical Depth vs Solar Zenith Angle (Liquid Water Clouds Over Ocean)



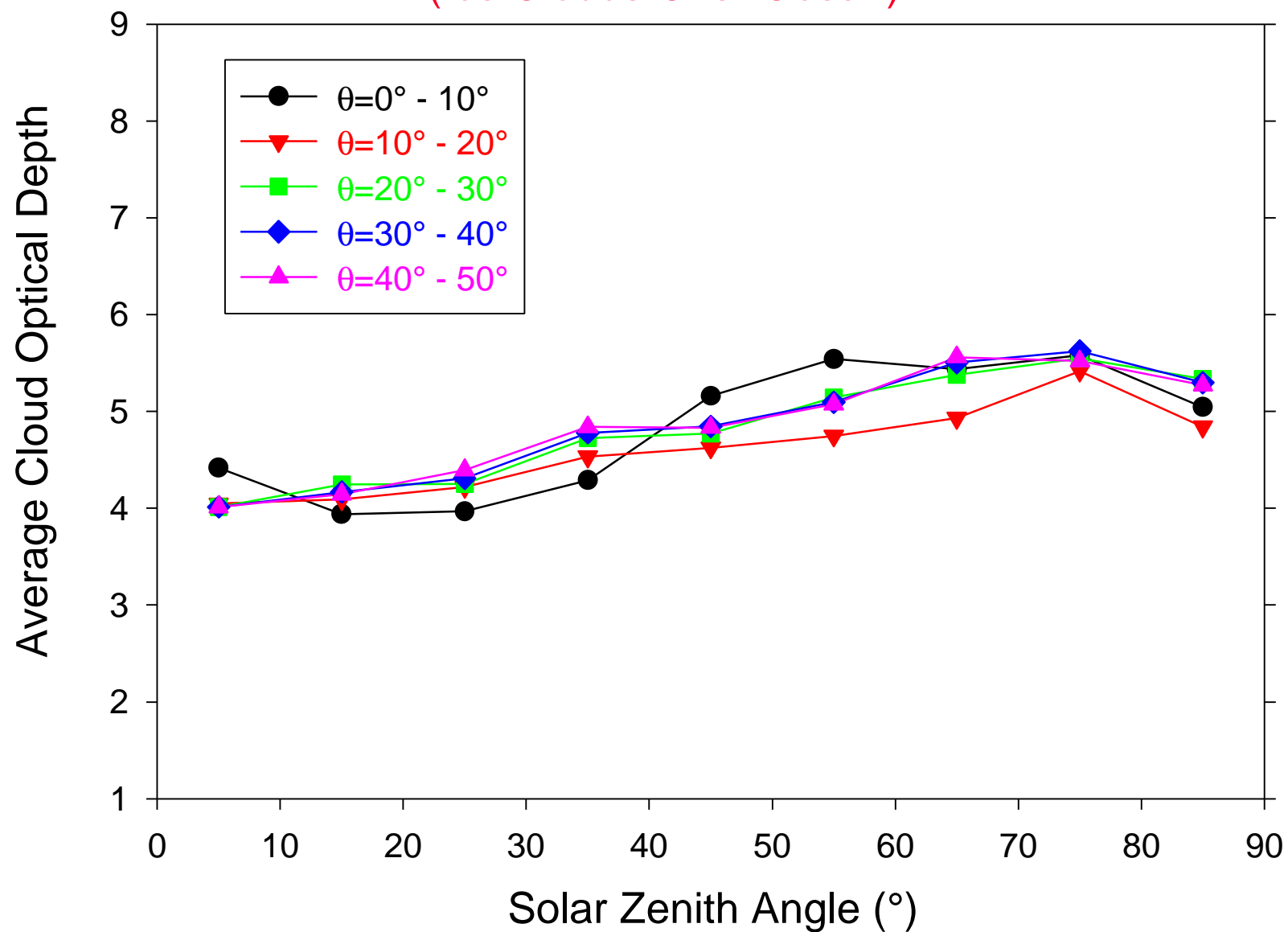
Tropical Average Adjusted Cloud Optical Depth vs Solar Zenith Angle  
(Liquid Water Clouds Over Ocean)



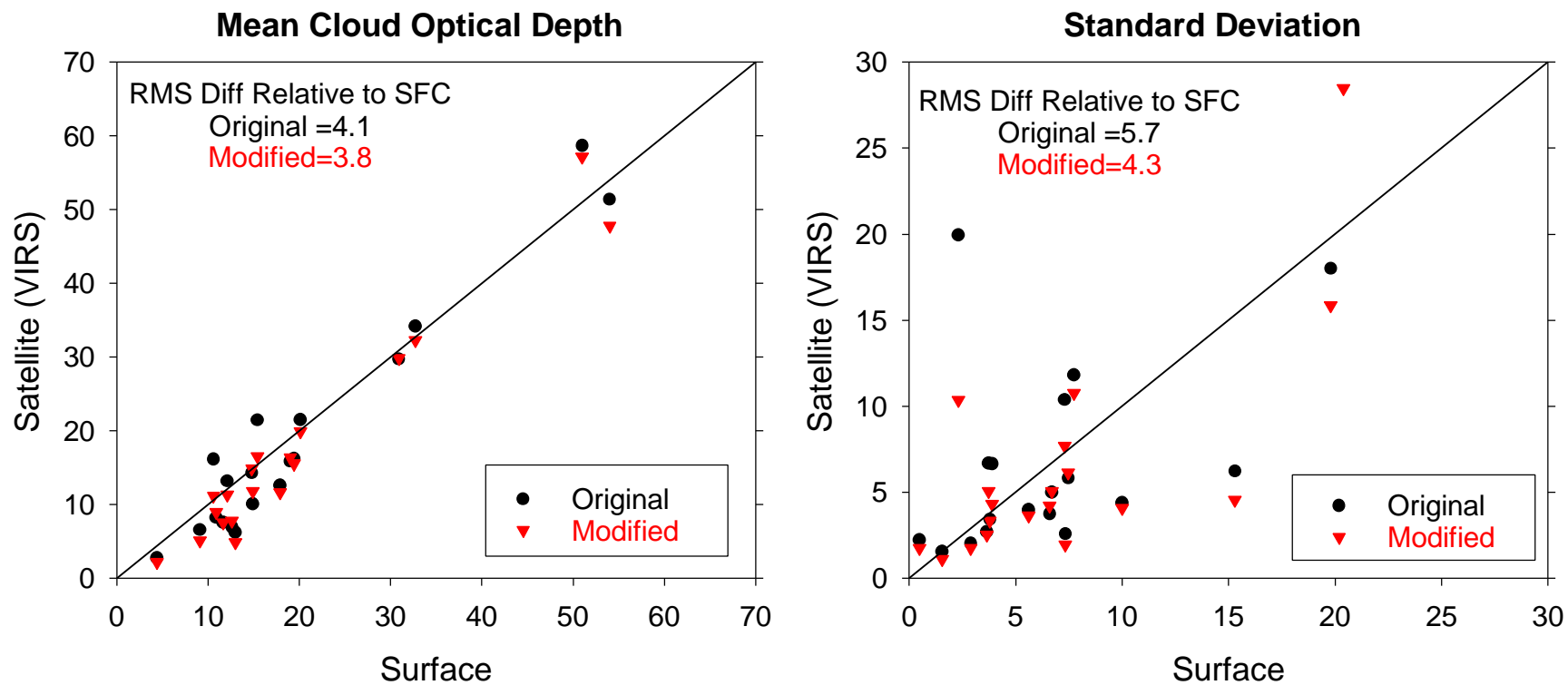
## Tropical Average Cloud Optical Depth vs Solar Zenith Angle (Ice Clouds Over Ocean)



Tropical Average Adjusted Cloud Optical Depth vs Solar Zenith Angle  
(Ice Clouds Over Ocean)



## ARM/SGP Cloud Optical Depth Comparisons: Stratus



## Summary

- i) A new method for reducing angle-dependent biases in satellite cloud optical depth retrievals has been developed.
- ii) Largest corrections occur for thick clouds at large solar zenith angles.
- iii) This approach will be used to develop CERES Angular Distribution Model (ADM) cloud optical depth classes.